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[54] **MULTI-COLOR, MULTI-PULSE LASER**

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[52] **U.S. Cl.** **372/97**; 372/17; 372/108

[58] **Field of Search** .... 330/4.3; 331/94.5 C, 331/94.5 M, 94.5 Q; 322/17, 97, 108

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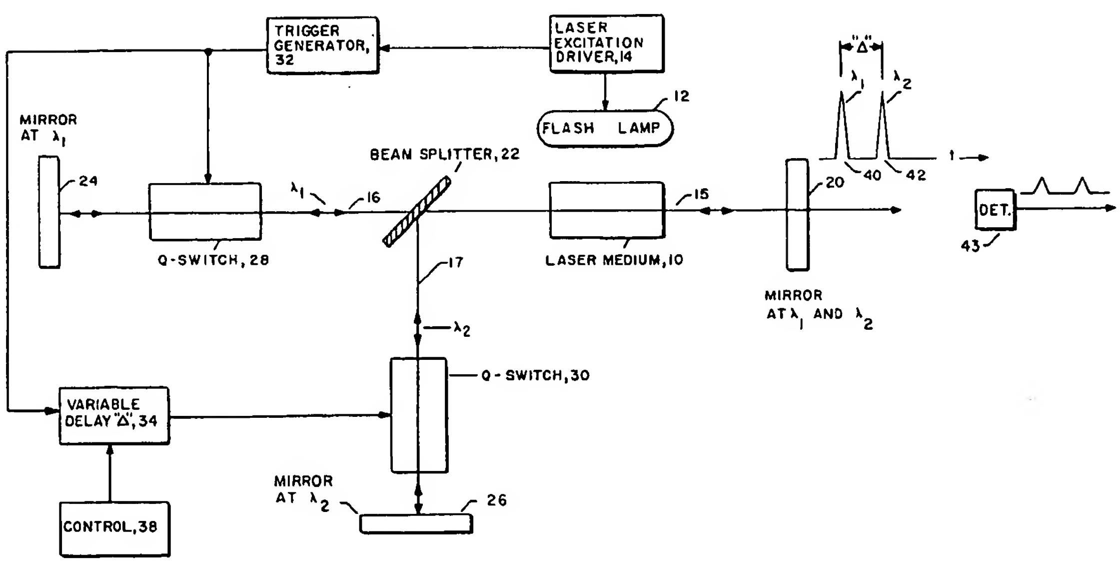
[57] **ABSTRACT**

A multi-color, multi-pulse laser operating at a number of wavelengths is provided with a like number of cavities to produce a like number of output pulses from a single pumping pulse. The spacing between the pulses is easily controlled by controlling the timing of Q-switches, each in a different cavity, so that information is imparted by the pulse spacing. In a two color embodiment, a beam splitting device is positioned along the longitudinal axis of the laser medium to produce two beams which are directed into different cavity resonators, each tuned to a different wavelength. Reflecting surfaces positioned at the end of each cavity redirect each beam back to the beam splitting device where the beams are spatially recombined and subsequently two pulses, one of one color and the other of the second color, are sequentially coupled out of the laser system. The colors may be sufficiently close in wavelength such that detection does not discriminate against the two colors, and a double pulse output is obtained at the detector. In this manner, the laser system produces two output pulses from a single laser medium and a single pumping pulse. The pulse width of each of the pulses may also be controlled by pulse stretching means in one or more of the optical paths.

16 Claims, 6 Drawing Sheets



wavelengths, it is a property of the radiation produced by the host material that radiation of one color is polarized in one direction, generally indicated by arrows 76, while radiation of the other wavelength is polarized in an orthogonal direction as illustrated by arrows 78. The other elements of the laser system illustrated in FIG. 5 are similar to those in FIGS. 3 and 4 with like elements being assigned like reference characters. In this embodiment, the non-Linear element 64 of FIG. 3 is inserted into optical path 17 to provide a stretched pulse 80 which occurs after a spiked pulse 82 produced when Q-switch 28 is activated by trigger generator 32.

The pulse width of pulse 80 is controlled by the variable driver power source 62, since the nonlinear element 64 is positioned in the cavity tuned to the λ_1 transition of the host material. The variable power source may be made to vary the power to the flash lamp in accordance with any intelligence to be transmitted.

In operation, upon optical pumping the laser host material lases producing an output at λ_1 and λ_2 with the λ_1 output being polarized for instance in a vertical direction, and the λ_2 output being polarized orthogonally as illustrated in a horizontal direction. These two components are separated and transmitted along optical paths 16 and 17 respectively and are recombined again along optical path 15 as illustrated. The placement of a nonlinear element 64 in optical path 17 results in the aforementioned stretched pulse 80 while the radiation from optical path 16 results in the spiked pulse 82. Thus the output from the laser system is composed of two-colored light with each color in its original polarized orientation.

In a still further embodiment an in-line multicolor, multipulse laser is illustrated in FIGS. 7 and 8. Referring to FIG. 7, in this embodiment a 20 laser medium 100 is illuminated with a flash lamp 102 driven by a suitable driver 104. This laser medium is located in a cavity tuned to the λ_1 transition of the laser which is defined by a partially reflecting mirror 106 at wavelengths λ_1 and λ_2 and a mirror 108 which is reflective at λ_1. A first Q-switch 110 is located between mirror 108 and laser medium 100 and is operated by driver 104 in accordance with the optical pumping of the laser medium. In one embodiment this Q-switch only gates λ_1 radiation because of the unique polarization of this wavelength due to the aforementioned birefringent effect. A Pockel's cell is such a Q-switch. Thus, in a preferred embodiment this Q-switch is a Pockel's cell polarized in the direction of the polarization of the λ_1 output from the laser medium. It will be appreciated that this type of Q-switch has very little, if any, effect on the λ_2 radiation from the laser medium. Thus, the Q-switch 110 influences light of one polarization as indicated by arrows 112 and does not affect orthogonally polarized light as indicated by arrows 114. In this embodiment, λ_1 is chosen to be shorter than λ_2.

The second laser cavity for the λ_2 wavelength of the laser is defined by mirror 106 and a mirror 116 reflective at the λ_2 wavelength of the laser, with a second Q-switch 118 interposed between mirror 116 and mirror 108. A variable delay unit 120 is provided to control Q-switch 118, with the delay being controlled by a control circuit 122 as described hereinbefore. It will be appreciated that mirror 108, while being substantially reflective at λ_1, is substantially transmissive at λ_2. Thus, Q-switch 110 and mirror 108 permit the in-line configuration by effectively being nonresponsive to the λ_2 wave length.

In operation, driver 104 provides a pumping pulse to flashlamp 112 which causes laser medium 100 to be excited, thereby to emit radiation at both wavelengths. Responsive to the pumping of the laser medium Q-switch 110 is actuated to gate λ_1 wavelength light to mirror 108 and then to block λ_1 radiation in the cavity tuned to λ_1 such that a first pulse having one polarization and one color, λ_1, is coupled out of the system through mirror 106. Thereafter, variable delay unit 120 actuates Q-switch 118 such that light at the λ_2 wavelength is gated to mirror 116 and then blocked. This produces a second pulse having a different polarization and color, λ_2, which is coupled out of the system through mirror 106. During this second Q-switching operation, Q-switch 110 and mirror 108 are effectively removed from the system and the effective cavity length is the distance between mirrors 106 and 116. Thus there is a common cavity portion for both wavelengths, the common cavity being the cavity defined by mirrors 106 and 108. Alternatively, Q-switch 110 may be gated on again with the gating on of Q-switch 118 such that any residual effect of Q-switch 110 on the λ_2 wavelength pulse is eliminated. This permits Q-switch 110 to be any of a variety of Q-switches.

Referring now to FIG. 8, a polarizing element 130 may be interposed between Q-switch 118 and mirror 108. This element is polarized in a direction to reject the λ_1 wavelength radiation while transmitting the λ_2 wavelength radiation to provide an added measure of isolation between the λ_2 and λ_1 wavelengths.

What has therefore been accomplished is the provision of a laser system which by virtue of its multicolor, multicavity configuration is able to produce multiple pulses with a high degree of control of both pulse spacing and pulse width. The number of pulses per individual flash lamp pulse is limited only by the number of wavelengths at which the laser host material lases and the number of cavities which are provided. Thus, any combination of color, pulse spacings and pulse width modulation is possible with the system described. Moreover because of the discovery that the light produced with a two color laser is polarized and orthogonally oriented, multiple pulses can be produced from lasers having the FIG. 2*b* transition configuration when rapid Q-switching is not available. Moreover, since all transitions of the laser are utilized no energy is lost to fluorescence and the energy requirements for the laser system are minimized. The versatility of the subject system is manifest in the type of control over the output of the laser and the unique ease with which the pulse parameters can be varied.

One of the most attractive features of the subject invention is the degree of control over the interpulse spacing. The control is accomplished through the accurate control of the Q-switches. Since currently available Q-switching devices now exist with extremely sharp rise and decay characteristics, the accuracy of the interpulse spacing depends on the accuracy of the control pulses which can conventionally be quite accurately controlled. Thus, interpulse jitter can be held low.

Although a specific embodiment to the invention has been described in considerable detail for illustrative purposes, many modifications will occur to those skilled in the art. It is therefore desired that the protection afforded by Letters Patent be limited only by the true scope of the appended claims.

We claim:

1. Apparatus for producing a beam of electromagnetic radiation containing pulses of different wavelengths comprising:

a laser medium which lases in at least two different wavelengths;

means for exciting said medium to lase in said at least two different wavelengths;

a number of laser cavities, each tuned to a different selected wavelength at which said laser medium lases;

means for coupling electromagnetic radiation of different selected wavelengths from said laser medium into different ones of said laser cavities;

separate Q-switching means in each of said laser cavities;

means for sequentially activating said Q-switching means to produce a number of different colored pulses spaced apart in time; and

means for forming an output beam from the electromagnetic radiation propagating in said laser cavities as a result of said sequential Q-switching, such that a number of said different colored time separated pulses propagate in a single direction.

2. The apparatus of claim 1 wherein said electromagnetic radiation coupling means includes a color selective beam splitter for directing radiation of one wavelength in one direction and radiation of another wavelength in another direction.

3. Apparatus for producing at Least two pulses of electromagnetic radiation of different wavelengths comprising:

a medium which is stimulated into emitting electromagnetic radiation in at least two wavelengths;

means for stimulating said medium into emitting electromagnetic radiation;

a number of cavities defined by reflective means at each end with said reflective means being spaced apart such that standing waves of electromagnetic radiation of a predetermined wavelength propagate between the reflective means in each of the cavities;

means for coupling electromagnetic radiation of different selected wavelengths from said medium into different cavities;

means for selectively permitting the propagating of electromagnetic radiation within at least one of said cavities; and

means for coupling the electromagnetic radiation propagating in said cavities out of said cavities such that pulses of electromagnetic radiation of different wavelengths are produced and projected in a single direction.

4. The apparatus of claim 3 wherein said selective electromagnetic radiation propagation permission means is a Q-switch responsive to radiation of only one particular polarization.

5. The apparatus of claim 3 and further including means for selectively permitting the propagating of electromagnetic radiation within each of said cavities.

6. The apparatus of claim 5 and further including means for sequentially activating said selective radiation permitting means to permit radiation propagation within a cavity for a predetermined length of time.

7. The apparatus of claim 6 wherein said sequential activation means includes variable time delay means for setting the sequential activation whereby the spacing between said multiple pulses is controlled by the setting.

8. The apparatus of claim 5 and further including means for simultaneously activating said selective radiation permitting means to permit radiation propagation within all cavities for a predetermined length of time thereby to produce overlapping pulses.

9. The apparatus of claim 3 and further including means for varying the pulse width of one of the pulses produced from radiation propagating in one of said cavities.

10. The apparatus of claim 9 wherein said means for varying pulse widths includes non-linear optical means in said one cavity and wherein said stimulating means includes means for coupling variable amounts of energy into said medium whereby the width of the pulse derived from said one cavity is controlled by the amount of energy coupled into said medium.

11. The apparatus of claim 10 wherein said energy is varied in accordance with information to be conveyed.

12. The apparatus of claim 6 and further including means for varying the pulse width of one of said pulses.

13. The apparatus of claim 6 and further including means for simultaneously detecting electromagnetic radiation of all of the wavelengths coupled out of said cavities and for producing a signal whenever electromagnetic radiation is detected, whereby said signal contains a number of pulses corresponding to the number of wavelengths received, the spacing of said pulses being commensurate with the time delay between said sequential activations.

14. A method of producing pulses of electromagnetic radiation having different wavelengths comprising the steps of:

providing a laser medium which lases at least two wavelengths;

exciting said laser medium to lase in said at least two different wavelengths;

coupling electromagnetic radiation of different wavelengths from said laser medium into different laser cavities;

forming an output beam from the electromagnetic radiation propagating in said laser cavities; and

sequentially permitting the transmission of electromagnetic radiation in different cavities responsive to the excitation of said laser medium to provide multiple pulses of electromagnetic radiation spaced apart in time in a single direction, each having a predetermined interpulse spacing depending on the sequence and each of a different color.

15. Apparatus for generating pulses of electromagnetic radiation of different wavelengths in an in-line laser configuration comprising:

a laser medium which lases in at least two different wavelengths when energy is coupled into said medium;

means for coupling energy into said medium;

a number of in-line laser cavity means each tuned to a different one of said wavelengths, said cavities being partially overlapping to form a common cavity;

means at the end of one of said common cavity for passing electromagnetic radiation from said laser medium having one wavelength while reflecting electromagnetic radiation having a different wavelength;

Q-switching means in each cavity for selectively allowing the transmission of electromagnetic radiation in the cavity;

means for selectively actuating said Q-switching means; and

means for coupling electromagnetic radiation propagating in said cavities out of said cavities, such that when said selective actuation is sequential, two differently colored pulses are formed.

16. The apparatus of claim 15 wherein the Q-switching means in the common cavity responds to radiation of only one color due to the polarization of this radiation.

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